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Quasiparticles Refuse to Go Away in High-Temperature Superconductors

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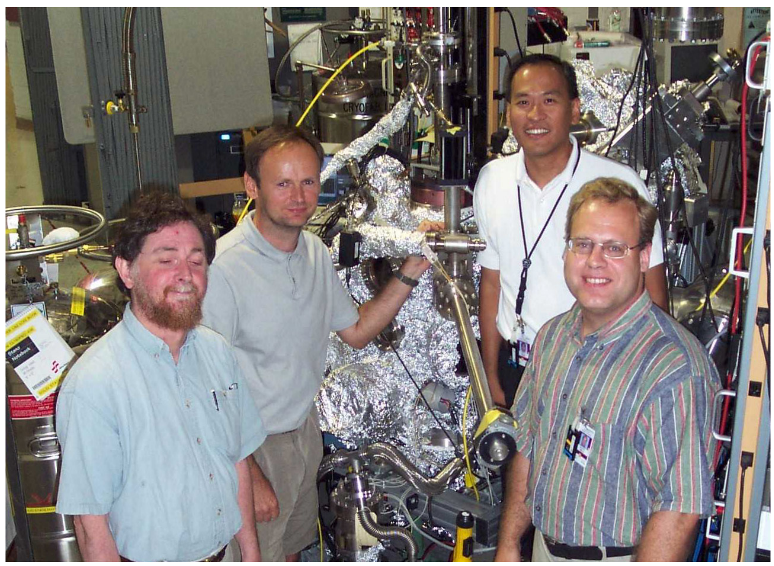
Scientists working at NSLS beamline U13UB have shown that provided new insight into the properties of overdoped cuprates (bismuth-strontium-copper-oxides). The researchers found that while underdoped cuprates have exotic properties, overdoped cuprates behave more like regular metals.



(From left) Peter Johnson, Tonica Valla, Zikri Yusof, and Barry Wells

Fifteen years after the discovery of cuprate (bismuth-strontium-copper-oxide) superconductors (1986), the origin of superconductivity in these materials is still unknown, and scientists are still investigating the nature and behavior of the charge carriers in these materials. One of the most studied of these compounds is $Bi_2Sr_2CaCu_2O_{8+\delta}$, also called Bi2212, which has provided considerable insight - as well as new puzzles - on the origin of high-temperature superconductivity.

Cuprates share a set of generic features. These compounds become superconductors only when they are doped with electrons or holes. Undoped, they are antiferromagnetic insulators. As they are doped either with holes or electrons, they evolve first into a strange metal and eventually become superconducting with increasing critical temperature T_c until this temperature reaches a maximum value at what is known as optimal doping. Increasing the doping level beyond this point causes Tc to drop again (Fig. 1). A doping level below the optimum value is known as underdoping, while that above the optimum value is known as overdoping.

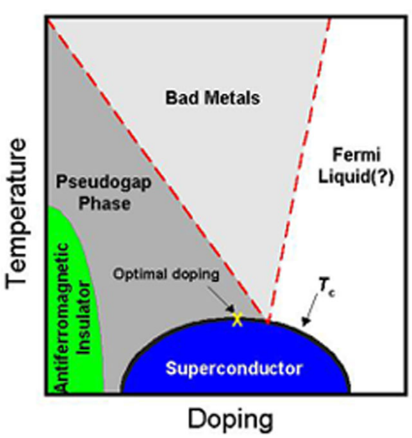


Figure 1. *Generic phase diagram of high-T_c superconductors.*

The underdoped and optimally-doped superconductors have a number of unusual properties, especially in the normal state (above T_c). One puzzling property is the apparent absence of "quasiparticles", entities that are defined in Landau's Fermi Liquid theory. This theory has successfully described the properties of ordinary metals, semiconductors and conventional superconductors (discovered before 1986), but cuprates, especially in their normal state, appear to defy explanation with this theory.

Samples of overdoped cuprates have been studied using angle-resolved photoemission spectroscopy (ARPES), which is a more sophisti-

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cated version of the familiar photoelectric effect. In ARPES, the outgoing photoelectrons are collected by an electron analyzer that allows us to obtain the energy and momentum distributions of these electrons. The presence of a quasiparticle gives a sharp peak in the ARPES spectrum.

We found that the superconducting state has quasiparticles at all doping levels but they persist to the normal state only for the overdoped compound (Fig. 2). We also established that while underdoped cuprates have exotic charge transport, the overdoped cuprates have more familiar quasiparticle physics - closer to a regular metal like copper. The next step is to understand how the material evolves from one form to another, either through a gradual crossover or a sharp phase transition.

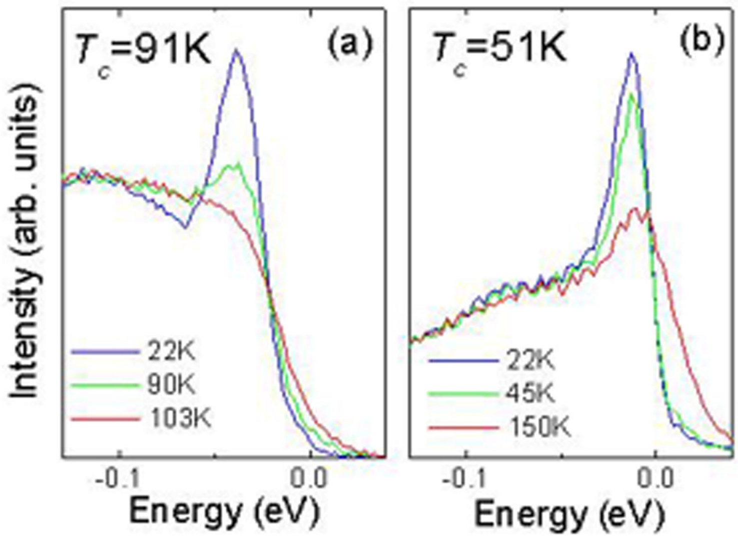

Figure 2. *Energy distribution of photoelectrons. (a) Optimally doped superconductor with T_c=91K. The sharp peak in the spectra, representing well-defined quasiparticles, is not detected above T_c [Fedorov et al. PRL 82, 2179 (1999)]. (b) Overdoped superconductor with T_c=51K. Sharp peak (quasiparticles) exists well above T_c.*